NASA TECHNICAL TRANSLATION

NASA TT F-14,730

METHOD AND EXAMPLE OF STUDYING AERIAL PHOTOGRAPHS OF THE NATURAL FRACTURING OF CARBONATES

P. Bouche and M. Poulet

Translation of "Methode et Exemple D'Étude Sur Photographies Aêriennes de la Fracturation Naturelle des Carbonates," *Revue de L'Institut Francais du Petrole*, pp. 33-21, Vol. 26, No. 1, 1971.

(NASA-TT-F-14730) METHOD AND EXAMPLE OF STUDYING AERIAL PHOTOGRAPHS OF THE NAUTRAL FRACTURING OF CARBONATES (Techtran Corp., Silver Spring, Md.) 25 p HC $4.25 CSCL 14E G3/14

N74-22108

Unclas 37863

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 MARCH 1973

STANDARD TITLE PAGE

1. Report No. NASA TT F-14,730	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle METHOD AND EXAMPLE OF STUDYING AERIAL PHOTOGRAPHS OF THE NATURAL FRACTURING OF CARBONATES.		5. Report Date 3/29/73
		6. Performing Organization Code
7. Author(s) P. Bouche and M. Poulet		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Techtran Corp., P. O. Box 645, Silver Spring, Maryland, 20901.		11. Contract or Grant No. NASw-2485
		13. Type of Report and Period Covered Technical Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Methode et Exemple D'Étude Sur Photographies Aériennes de la Fracturation Naturelle des Carbonates" Vol. 26, No. 1, 1971, pp. 1-21.

16. Abstract

This article contains the leading methodological information provided by the aerial photograph examination of natural fracturing of carbonates in two areas of northern Algeria: The Djebel Onk and the Djebel Nador.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified-Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	25	4.25

METHOD AND EXAMPLE OF STUDYING AERIAL PHOTOGRAPHS OF THE NATURAL FRACTURING OF CARBONATES[1] /3*

P. Bouche and M. Poulet[2]

This article contains the leading methodological information provided by the aerial photograph examination of natural fracturing of carbonates in two areas of northern Algeria: the Djebel Onk and the Djebel Nador.

The first part of the article examines the various problems occurring at successive stages of the survey: photography, including choice of scale and photographic emulsions; analysis of the photographs; definition of fracturing characteristics by means of optical filtering.

The second part gives an example of how the above method is applied in surveying fracturing of an anticline structure such as Djebel Onk. The data obtained and a general knowledge of the geological context permit proposing an interpretation of the results. This interpretation must then be confirmed by on-the-site observations.

I. INTRODUCTION /4

1.1 Scope of the Study

This paper presents the principal methodological information which was drawn from a study of natural carbonate fracturing by means of aerial photographs. It resulted from the Natural Fracturing Study which began in Algeria at the start of 1968 within the framework of the ARTFP. The goal was to determine the distribution of fractures in the carbonated rocks for various types of structure to predict favorable areas in the development of a field.

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[1]This study was made within the ARTFP program in 1968 and 1969 and was reported on at the Petroleum Exploitation Methods Research Association held at the French Petroleum Institute in Rueil-Malmaison from June 7 to 9, 1971 (paper no. 40).

All of the reports presented at that Colloquium, as well as for the last three colloquia will be on sale at Editions Technip in the first half of 1972.

[2]From the French Petroleum Institute.

*Numbers in the margin indicate foreign text pagination.

For this purpose the examination of the aerial photographs should be combined with field studies. The unexpected end of the project unfortunately made field observations impossible. The study was thus limited to picture taking and utilization of the pictures of two areas of northern Algeria. These areas, selected because of their outcropping conditions and their structural characteristics, are, respectively:

- a monoclinal area marked by transverse cracks to the south of Djebel Nador (Algerois) situated 250 km SSW of Algiers (area of approximately 240 square kilometers);
- an anticline structure of the South Constantinois located 1400 km south of Tebessa: the Djebel Onk (area of about 115 square kilometers).

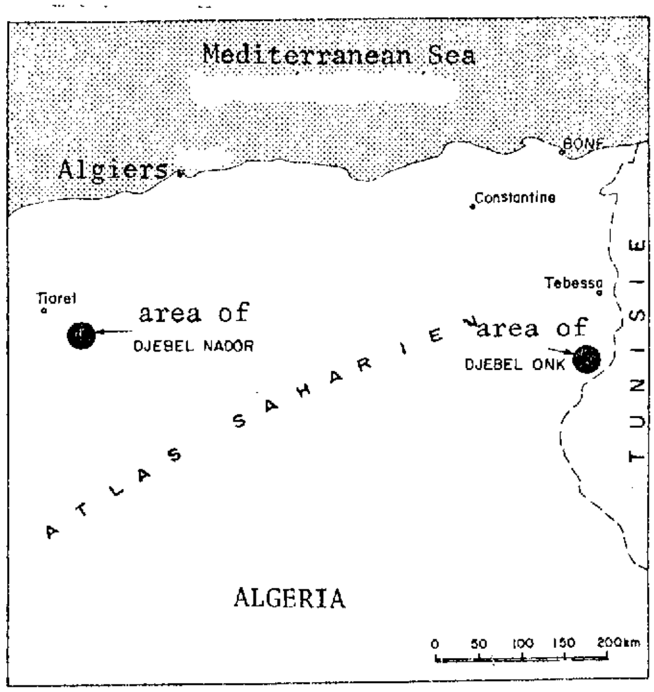


Figure 1. Location of the Areas Studied On Aerial Photographs.

1.2 Reason and Purpose of the Study /5

Two purposes for the value of such work come to mind:

- the fractures which are of interest to the production engineer are not only the large-scale fractures but above the small-scale

ones (called fissures here) which are decimeters in size and not visible on aerial photos;
- the observations are made at the surface either plumb with the deposit or on the outcroppings of the productive level. Can these data be validly extrapolated to the deep productive reservoir?

These factors can be answered by the following arguments:
- the fissures (small in size) and the fractures (large in size) are often combined: local and not too numerous observations made on the terrain at selected sites permit defining these relationships; we can thus deduce from this the distribution of the small-size fractures with respect to the entire area studied by means of aerial photos;
- it is not a matter of roughly extrapolating the surface data to the deep productive horizon. The characteristics of the fractures visible on the photos and a knowledge of the geological context will enable us to define the age, direction and nature of the constraints which caused the fractures and associated fissures. These are the factors which will be taken into consideration to define the deep fracturation, as well as the parameters proper to the productive reservoir (resistance to breaking under pressure or compression, geostatic pressure, pressure of the fluids).

In this specific case which we are concerned with, a complete interpretation of the data obtained from the aerial photographs was not possible because of the absence of field observations. We therefore attempted above all to solve the various problems presented at the successive stages of the study:
- the photography: selecting the scale and photographic emulsion;
- the analysis of the photograph;
- the utilization of the analytical documents: definition of the fracturing characteristics by means of optical filtering.

These are the various points which will be examined in the following section. In the second part of the report we will discuss an example of application of this method: study of Djebel Onk.

II. METHODOLOGY

II.1 Technical Examination of the Pictures

Various pictures were examined and compared for the purpose of defining the emulsion as well as the photographic scale which are most appropriate for detecting fractures.

II.1.1 Photographic Coverage

The following emulsions were used:

- black and white emulsions:
  panchromatic: Kodak Plus X aviation;
  pseudo-orthochromatic: Kodak Plus X aviation with partial filtering of the red to obtain better shades in the rest of the spectrum.
- color emulsions:
  Kodak aviation ektachrome;
  Infra-aviation Ektachrome (false color).

This is a color film in which the red-sensitive layer was replaced by an infrared-sensitive layer. This emulsion permits visualization of the reflecting power of plants in the infrared (I) by a fictitious change of color, hence its name, false color. /6

These four emulsions involved two coverages at 1/10,000 each one of which included two emulsions: one in black and white and one in color or false color. Furthermore, a partial coverage at the scale of 1/5,000 was done on each perimeter. The black and white emulsions were printed on glossy paper and the color emulsions were developed as slides.

II.1.2 Appearance of the Fracturing

The outline of the fractures is particularly clear in the limestones of Djebel Onk (Figure 2). In the marly-chalky formation of Djebel Nador the fractures often appear as discontinuous outlines accompanied by alignments of vegetation (Figure 3). Finally, in the magnesian limestones of Djebel Nador the erosion, although it emphasizes the fracture nature of the rocks, causes part of the fractures to lose their individuality (Figure 4). In color they appear as lines of dark brown color, sometimes greenish; in fictitious color these are dark green to reddish brown outlines.

II.1.3 Comparison of the Emulsions

The emulsions were compared with one another by analysis of fractures revealed on corresponding view under identical observation conditions.

Figure 2. Djebel Onk: Limestock Fractures Of Upper Cretaceous (scale 1/10,000, panchromatic).

For this analysis four categories of fractures were distinguished as a function of their length (L): /8

$L \geqslant 300$ m; $100 \text{ m} < L < 300$ m; $50 \text{ m} < L < 100$ m; $L \leqslant 50$ m.

Seven photos where various types of formations were plentiful (calcareous formations of Djebel Onk, dolomites and marno-calcareous of Djebel Nador) were examined. The calculations were then carried over to graphs of the type in Figure 5, thus permitting quick visual comparison.

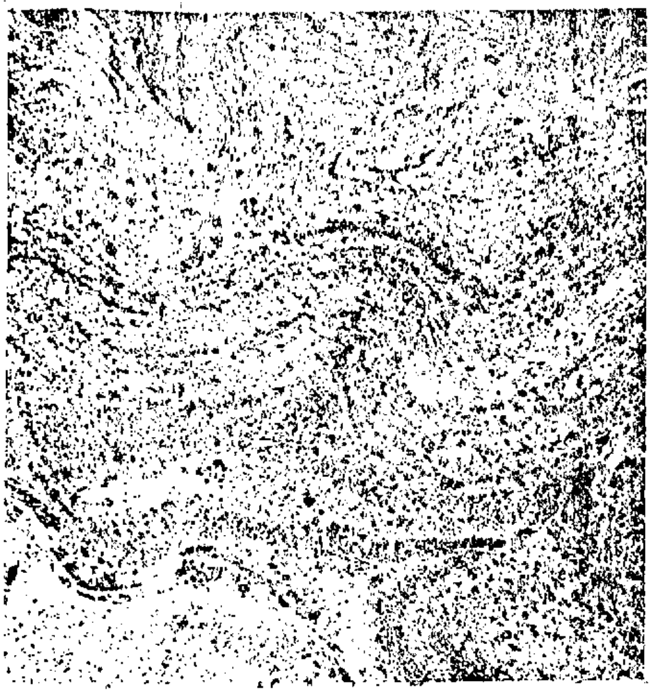


Figure 3. Djebel Nador: Calcareous Marlo Fractures of Portlandian (scale 1/10,000, panchromatic).

/7

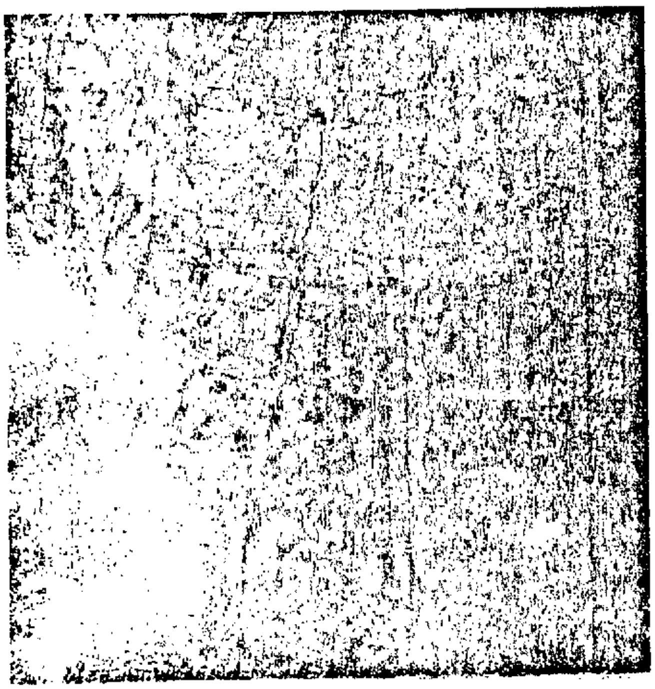


Figure 4. Dolomite Fractures of Kimmeridgien (scale 1/5,000, panchromatic).

The following conclusions were reached: /8

- the pseudo-orthochromatic emulsion does not present any advantage over panchromatic;

- the color and fictitious color emulsions allow better detection of the small fractures (L less than 50 meters), the increase in number exceeds 50% in five out of seven cases for this category (Figure 5);
- the false color emulsion is better than the color emulsion for all of the fractures smaller than 100 m; this improvement is particularly significant for small fractures.

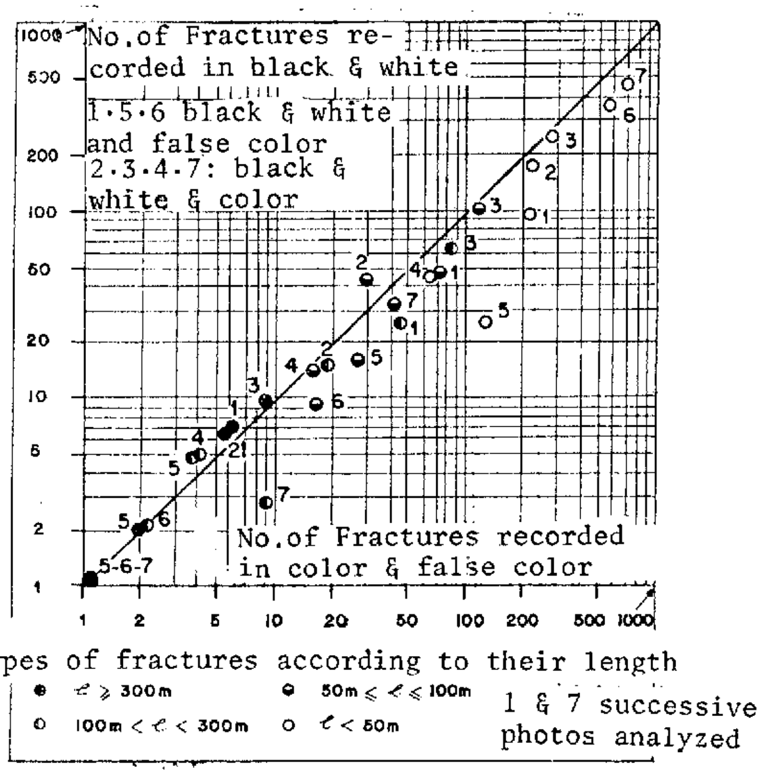
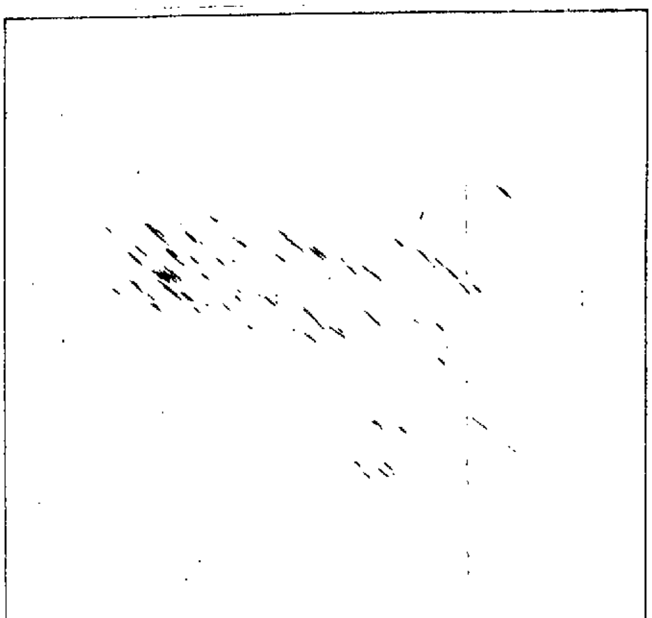


Figure 5. Comparison Between Color, False Color and Black and White Emulsions.

We also compared the results obtained on paper impressions (black and white) and the corresponding slides. Examination of the slides promotes the inventory of small-size fractures (gain of 50%).

[Translator's Note: Page 9 of original is missing from text received].

selected. If desired, it is also possible to obtain a filtered image of the document for each direction (Figure 6). The extent of the light intensity is proportional to the cumulative length of the fractures with respect to a given /10 mean direction. These measurements made for the entire range of directions and different dimensional types of fracture permit characterizing in relative value the direction and intensity of the fracturing for a given geographical area.[1]



Fractures Between Angles of N 110° E And N 120° E

Figure 6. Djebel-Onk (West Sector): Filtered Images (By 10° Sector) Due to Inventory of Fractures of Length Less than 100 m.

II.3.2 Direction of the Fractures

If we place in relative value (5) the measurements made in each mean direction on a rosette diagram then for a given type of fracture we obtain the distribution of the fractures as a function of the azimuth (Figures 7 and 8). On the diagram of Figure 8 we also plotted the data obtained by directly analyzing the photo by optical filtering (Figure 4). This very fast method cannot be applied generally, unfortunately, because of the usual presence of

[1]All of the optical filtering operations were done in the geophysics division of the French Petroleum Institute under the supervision of Mr. Fontanel.

alignments alien to the fracturing (limits of the strata, artificial vegetation, hydrographic network). In this specific case (Figure 4) we notice that the two frequency diagrams (Figure 8) reveal identical preferential directions. We note, however, that the direct analysis of the photos is sharper and reveals a secondary direction not mentioned in the inventory.

Figure 7. Djebel Nador: Inventory of the Fracturing of the Dolomites (Figure 4)

II.3.3 Intensity of the Fracturing /12

For a given surface element the intensity of the fracturing can be defined by the cumulative length of the fractures crossing it, with or without consideration of their direction. A magnitude proportional to this parameter is obtained by measuring the light intensity by optical filtering. By splitting up the area studied into small surfaces analyzed successively we can trace curves of equal density of fracturing, either total or directional for the parameter studied. This splitting up can be done taking into account the lithology of the layers, their dip, thus making it possible to study the effect of these parameters. Likewise we characterize the mean length of the fractures by the relationship between the light intensity and the number of fractures counted on a given surface. These detailed analyses were not made in this study because of lack of time but they do not present any technical difficulty.

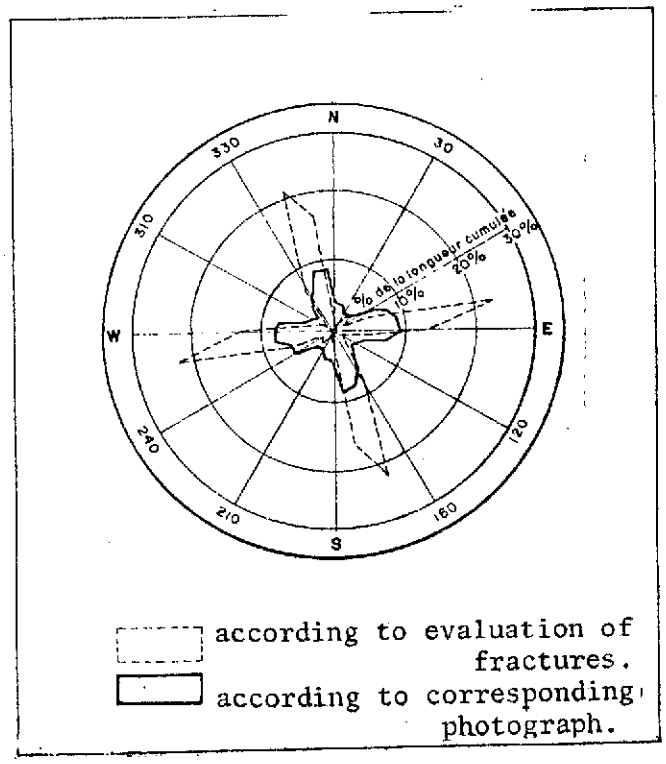


Figure 8. Djebel Nador: Distribution of the Fracturing in the Different Azimuths From the Evaluation of Figure 7 and From the Direct Analysis of the Photo (Figure 4) By Optical Filtering

III. EXAMPLE OF APPLICATION: DJEBEL ONK

III.1 Geological Framework

III.1.1 Geographical and Geological Situation

The anticline structure of Djebel Onk is situated between the Nemencha mountains and the Tunisian border, about 100 km south of Tebessa (Figures 1 and 9).

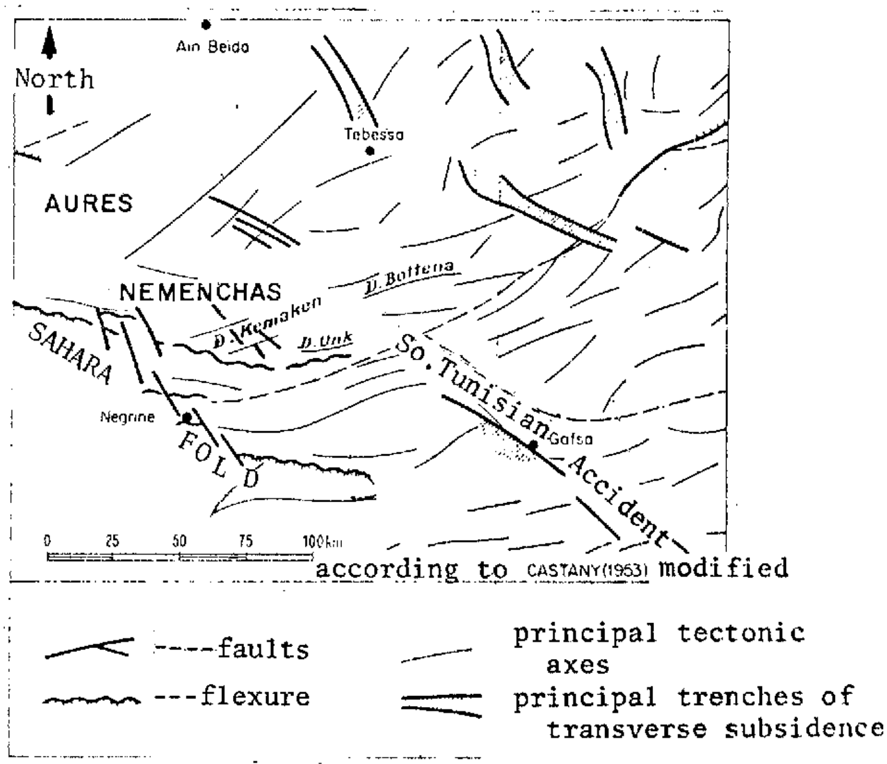


Figure 9. Tectonic Map of the South Constantinois

Since 1959 this gave rise to petroleum drilling which yielded a small production of oil coming from limestone deposits, the permeability of this reservoir being connected primarily with the fracturing. /13

The leveling in this study corresponds essentially to the limestone core antichnal over a length of 17 km and an average width of 2.5 km. A thickness of sediments of about 1,000 meters separates it from the productive reservoir.

The Djebel Onk is located at the southern edge of the Atlas Mountains in the vicinity of the Sahara fold (Figure 9). In this region the folds have a predominant east to west direction. They are generally asymmetrical and slope towards the south. They are sometimes made uneven by longitudinal faults and are often cut across by large transverse checks (faults, grabens) oriented in the NW-SE direction (4).

III.1.2 Structural Characteristics of Djebel Onk

This anticline has a general E-W direction with a slightly curved axis (concavity turned northwards) showing two high points (culminations) (Figure 10). It is very asymmetrical: its northern flank is not very sloped (20° maximum), whereas its S-E flank is sudden, sometimes locally inverted. The principal faults which give a broken appearance to the anticline are either the E-W faults or the NW-SE faults. These two systems sometimes connect. Based on the geological work done in the region (5) (6) we can distinguish two principal tectonic phases:

- an antemiocene phase: to the NE and SE of the structure the continental miocene is discordant on the lower eocene and folded center;
- a more recent phase attributable to the postpliocene epoch which is presumably responsible for the large transverse accidents indicated above (Figure 9).

III.1.3 Lithology and Stratigraphy

The limestones which form the arch of the anticline are of the Maestrichtian period (upper Cretaceous). These massive limestones, cretaceous, slightly argillaceous and dolomitic are about a hundred meters thick. Cropping out on the periphery are the overlying marly formations of the lower Eocene Epoch. The axial zone of the structure is open in the limestones except for the western part where the overlying marly formation crops out.

III.2 Characteristics of the Fracturing

III.2.1 Analytical Data

The data obtained from the photos were retranscribed on an enlargement to 1/10,000 of the topographic map at the scale of 1/100,000. Figure 11 is extracted from this document. Since the orientation of the small fractures is much more dispersed than that of the large fractures, three dimensional categories of fractures were distinguished during the transfer: length less than 100 meters, length between 100 and 300 meters, and length greater than 300 meters. Furthermore, the perimeter was divided into two zones, an eastern zone and a western zone (Figure 10). Then six documents were subjected to optical filtering and this made it possible to obtain:

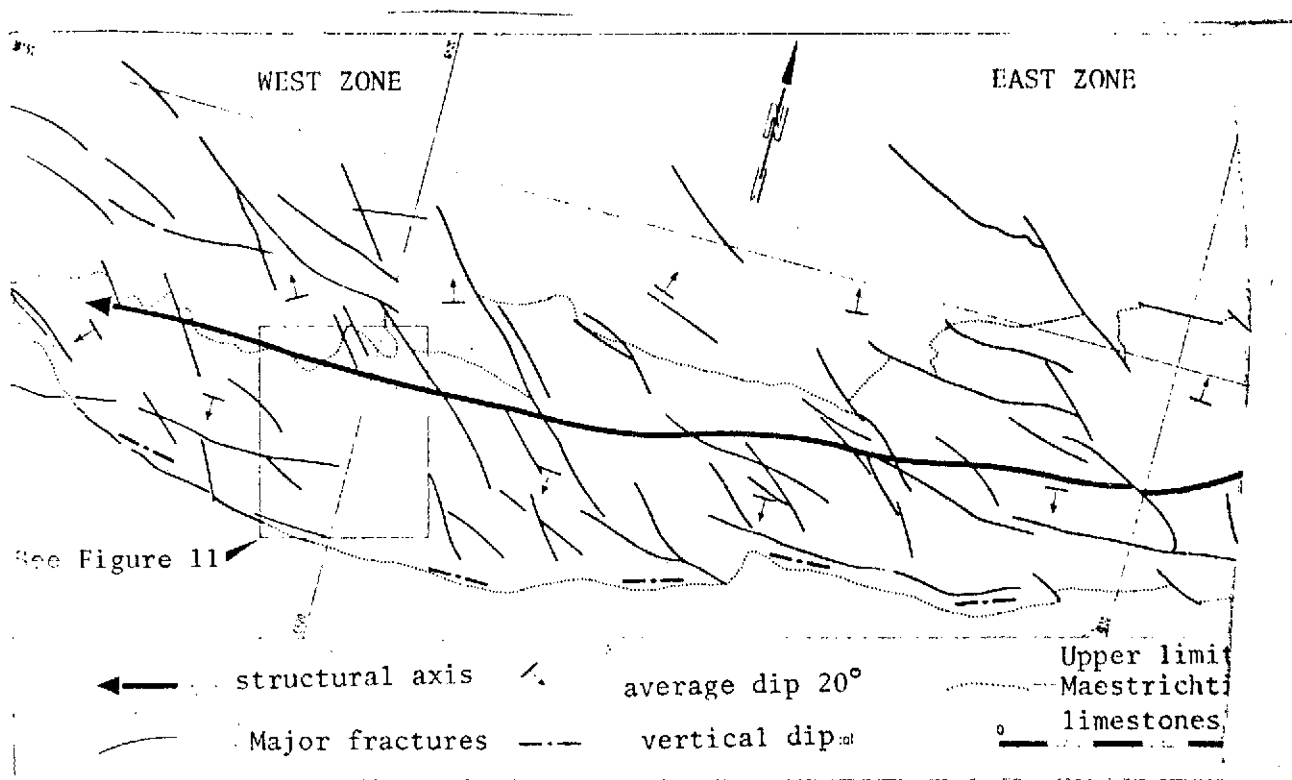


Figure 10. Structural Map of Djebel Onk

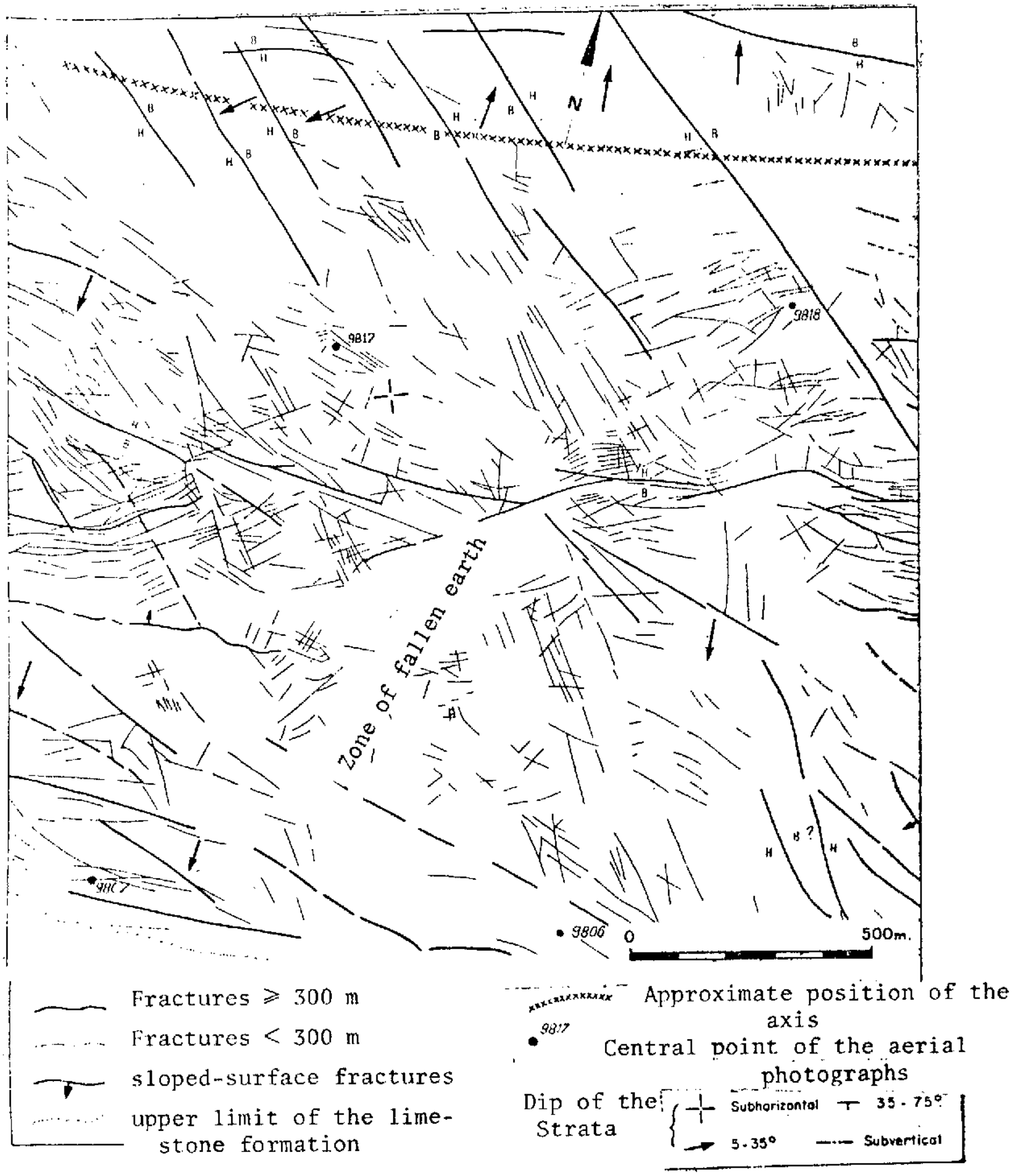
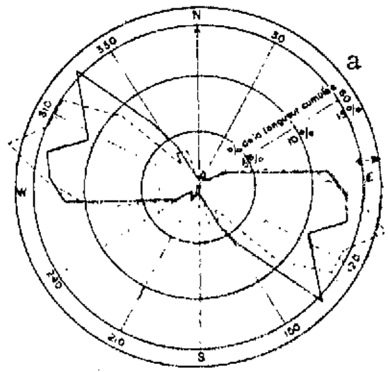


Figure 11. Djebel Onk: Evaluation of the Fracturing From 1/10,000-scale Photos

Distribution of the Fractures Greater Than or Equal to 300 m in the Various Azimuths (class of 10°)

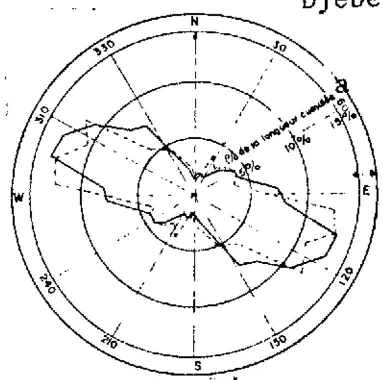


↔ General direction of the anticline axis

▭ Western zone of Djebel Onk

⬚ Eastern zone of Djebel Onk

Distribution of the Fractures From 100 m to 300 m in the Various Azimuths (class of 10°)

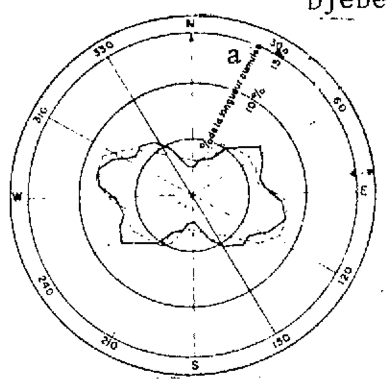


↔ General direction of the anticline axis

▭ Western zone of Djebel Onk

⬚ Eastern zone of Djebel Onk

Distribution of the Fractures Less Than or Equal to 100 m in the Various Azimuths (class of 10°)



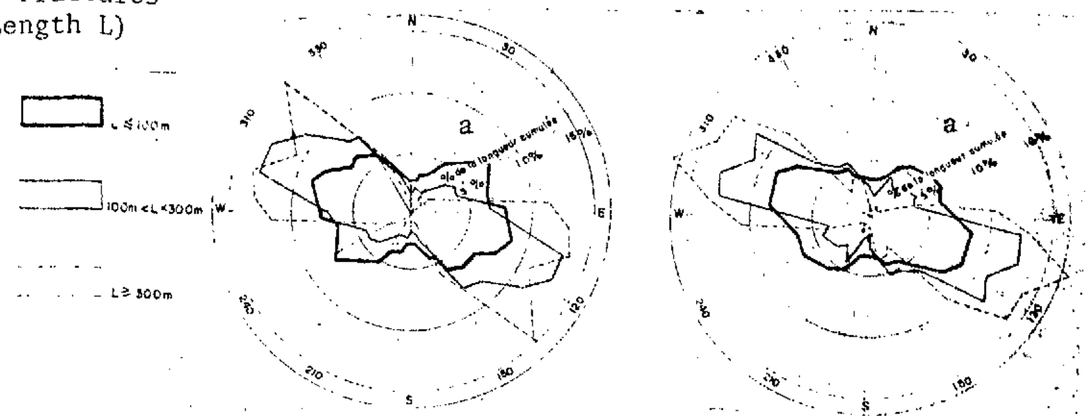
↔ General direction of the anticline axis

▭ Western zone of Djebel Onk

⬚ Eastern zone of Djebel Onk

Figure 12. Djebel Onk: Comparison of the Distribution of the Fractures in the East and West Sectors For Each Dimensional Category. a, % of cumulative length.

Categories of Fractures (Length L)

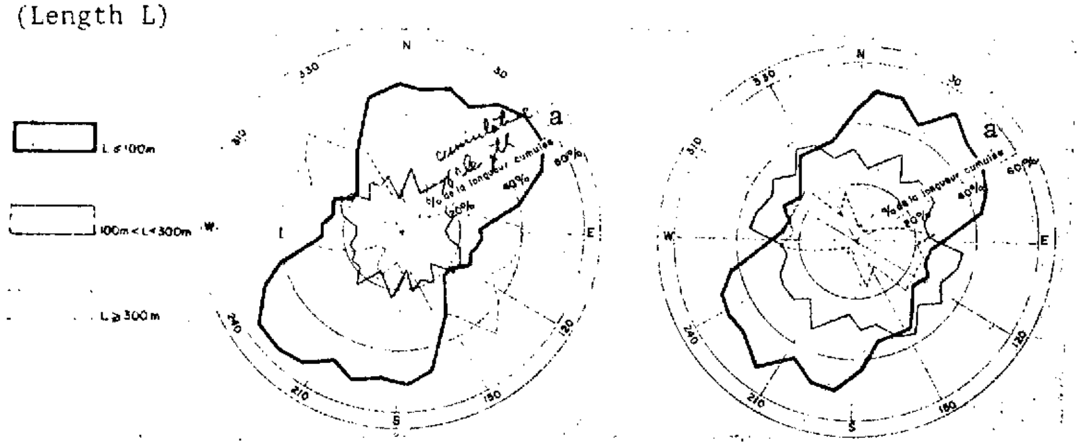


Zone West

Zone East

Figure 13. Djebel Onk: Distribution For Every Sector Of Fractures of Different Dimensional Categories. a, % of cumulative length.

Categories of Fractures (Length L)



Zone West

Zone East

Figure 14. Djebel Onk: Distribution of Relative Intensities of Fracturing For Every Dimensional Category From East and West Sectors. a, % of cumulative length.

- six frequency diagrams defining the orientation of the fracturing for each dimensional category and each zone (Figures 12 and 13);
- six frequency diagrams (three for each zone) giving the relative intensity of the fracturing related to each dimensional class for a given direction (Figure 14).

Examination of the synthetic documents at 1/10,000 and of these diagrams enabled us to define the fracturing characteristics.

III.2.2 Orientation of the Fracturing /17

The longest fractures are generally vertical. It was assumed that this feature extended to the entire fracturing although the slope of the small fractures cannot be determined.

The diagrams in Figure 12 show that regardless of the category of fracture there is an identical distribution for the east and west zones. In order to determine the degree of similarity we analyzed a sample of limited size and we found a distribution which was identical to that presented by the entire perimeter with less scatter.

The fractures longer than 300 m (comprising most of the fractures /18 recognized as faults) and the fractures between 100 and 300 m have an identical distribution (Figure 13). In both cases a large part of the fracturing (75% and 60%) is located in the area between North 80° E and North 140° E. In this sector the distribution tends to have two modes. This two-mode characteristic could reflect what is shown by examining the fractures (Figures 10 and 11), i.e., the existence of two directional families: one close to the general direction of the axis and the other oblique to that direction.

For the small fractures (less than 100 m long) the distribution is much more scattered. There are two predominant directions (Figures 12 and 13), one identical to that of the large fractures and the other symmetrical to the preceding one with respect to the axis of the structure (North 60° E).

Let us also point out two secondary fracturing directions which appear rather clearly in the distribution of the medium and large fractures North 25° E, North 25° W (Figures 12 and 13).

III.2.3 Intensity of the Fracturing

Figure 14 shows the intensity of fracturing corresponding to each dimensional category in the two zones East and West in relative value (%) for each direction. We note that the proportion of the same category of fracture in a given direction varies from one area to another but that the evolution of this proportion as a function of the direction remains the same in the two diagrams.

The relative size of the large fractures is greatest in the sector North 80° E to North 140° C and smallest in the sector North 10° W to North 70° E which corresponds to a relative maximum size of the small fractures. The relative size of the medium fractures (100 to 300 m) is practically constant in all directions.

We can assume from this also that regardless of the direction the number of small fractures (N_1) is greater than the number of medium fractures (N_2) and, in turn, the number of medium fractures is greater than that of the large fractures (N_3). A rough estimate by default based on medium lengths of 100, 200 and 300 m for the three categories yields, for example for the Eastern zone (Figure 14):

- in the sector North 80°E to North 140°E $\frac{N_1}{N_3} > 3$ and $\frac{N_1}{N_2} > 2$;
- in the sector North 10°W to North 70°E $\frac{N_1}{N_3} > 30$ and $\frac{N_1}{N_2} > 4$.

III.2.4 Characteristics Peculiar To Fractures Longer Than 100 m

Examination of the synthetic documents at scale of 1/10,000 which are not presented here made it possible to make a certain number of remarks on the fractures greater than 100 m in size.

The longitudinal fractures, that is to say those parallel to the axis by about 10° which comprise 23% of the fracturing involving above all the southern flank of the structure where they can make up extensive faults (Figure 10): these faults appear to be normal; their throw, which could not be accurately estimated however, seems undoubtedly great.

The fractures which are oblique with respect to the axis represent the essential part of the network. A large number of faults with small vertical throw (less than 25 m) is found there; several involved a transverse fault; horizontal movements are evident to the east on the straightened southern flank.

Some fractures are relayed not far from their termination by fractures /19 which have a different orientation or which present a considerable change in direction but in no case does it seem that a system of fracture is subordinated to another.

It has also been noted that the middle part of the limestock arch seems much more fractured than its extremities.

III.3 Attempt at Interpretation

The regional fracturing studies are for the purpose of revealing the distribution logic of the fractures, that is to say to define the relationships which exist between this distribution and the distribution of constraints which have developed during the subsequent tectonic phases. In this specific case the absence of field observations makes a true interpretation impossible. Furthermore, this is not a simple problem since the structural history of the region leads to distinguishing at least two different tectonic phases.

Nevertheless, based on the facts presented above we propose the following hypothesis as an explanation. The presently observed fracturing state is due to two constraint states related to the two tectonic phases.

First Phase of the Antemiocene Age

It causes a significant east-west folding of the axis. This implies that the principal maximum constraint (compression) which caused the formation of this fold is of the north-south direction. At the Maestrichtian limestone situated at a maximum depth of several hundred hours during the folding and constituting an external arch of the fold we can expect to find a local pressure constraint perpendicular to the axis. This constraint will constitute the principal minimum constraint of north-south direction, the principal average constraint due to the weight of the terrain will be vertical and the maximum principal constraint will be parallel to the axis of the fold.

The result of this should be:

-longitudinal pressure fractures perpendicular to the direction of minimum constraint, these fractures being more developed in the area of maximum curvature of the limestock arch, i.e., at the southern flank in the vicinity of the axis (7).

-shear fractures which develop in planes parallel to the direction of the average principal constraint and forming an angle less than 45° with the direction of maximum principal constraint (8). In the present case these fractures would form an angle of about 25° with the direction of the axis. There is no reason *a priori* for a direction to be predominant with respect to its conjugate direction (symmetrical with respect to the axis).

After this first tectonic phase, therefore, we would have:

-longitudinal pressure fractures parallel to the axis of the fold;

-shearing fractures distributed according to two conjugate directions forming an angle of 25° with respect to the axis of the fold, i.e., North 60° E and North 110° E.

This case is completely similar to that studied by De Sitter in a neighboring region of Eastern Algeria (9).

Second Tectonic Phase of Postpliocene Age

From the first tectonic phase there follows a certain number of planes of anisotropy of approximate direction North 60° E, North 85° E, North 110° E on the structure at the level of the Maestrich limestone. These planes will constitute zones of smaller resistance if the structure is subjected to a new state of /20 constraint and there will be preferential fracturing following these planes to the extent that the direction of the maximum principal constraint (compression) forms a certain angle with their direction. The theoretical studies (8) and the laboratory tests (10) (11) lead to identical conclusions: the shearing occurs according to the anisotropy plane when the inclination of the maximum principal constraint is between 0 and 45° with respect to this plane. The resistance to breaking will be minimum at a value of 30°. But we note that there is presently a preferential orientation of fractures in the direction

North 110° E for the fractures longer than 100 m, which means that the fractures North 110° E created by the first tectonic phase are the ones which were preferentially replayed, the small fractures (North 60° E) not replaying at all. Two possible mean orientations can be assumed for the maximum principal constraint (compression) during the second tectonic phase: North 80° E and North 140° E, forming an angle of 30° with the direction of maximum fracturing (North 110° E). The North 80° E direction seems rather unlikely in view of the presence of grabens to the east of Djebel Onk (Figure 9) which result in a pressure constraint in the same direction. Thus, during this second tectonic phase the following would have occurred:

- a maximum horizontal principal constraint (compression) of direction North 140° E;
- a maximum principal constraint (pressure) perpendicular to the first, of direction North 50° E;
- a vertical average principal constraint due to the weight of the terrain and probably small.

This attempted interpretation would have to be verified and rendered more precise by field observations of the fractures (open or closed nature; presence of mineralization, stria; replay of already mineralized fractures). Only after these field observations can we apply the preceding results to the fracturing of the productive reservoir.

IV. CONCLUSIONS

This work contributed a certain amount of information on methods of using aerial photographs for studying natural fracturing:

Emulsion and Photography: Color emulsions, and above all fictitious color emulsions, are of definite value in detection of fractures of small dimensions (less than 50 meters). The scale of 1/10,000 for the photographs is the most appropriate average scale for studying the various types of fracture.

Categorizing of Fractures: The method adoped for grouping the partial data, i.e., the carry-over to enlarged topographic base, proved to be acceptable and low in cost. It has been shown that in certain cases direct optical filtering of the photographs could result in a more objective catagorization (inventory) of the fracturing than manual development.

Use of the Analytical Results: Optical filtering appears to be an effective method for determining the characteristics of the fracturing. All of its possibilities have not yet been put to use.

Interpretation of the Results: The results obtained at Djebel Onk illustrate the possibilities and limitations of this method of study well. Knowledge of the structural evolution of the area studied, as well as field observations, are essential to reconstruct the constraint states to which the rock has been subjected and to define the probable characteristics of the fracturing in the deep productive reservoir.

Report received in May 1971

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Translated for the National Aeronautics and Space Administration under contract No. NASw-2485 by Techtran Corporation, P. O. Box 645, Silver Spring, Maryland, 20901. Translated by: Stephen Savage.